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(54) **POWER TRANSMISSION SYSTEM OF HYBRID ELECTRIC VEHICLE**

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B60K 6/445 (2007.10)
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CPC **B60K 6/365** (2013.01); **B60K 6/387** (2013.01); **B60K 6/445** (2013.01); **F16H 3/728** (2013.01); **B60K 2006/381** (2013.01); **Y10S 903/902** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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(57) **ABSTRACT**

A power transmission system of a hybrid electric vehicle may include: an input shaft receiving torque of an engine; a first rotation shaft disposed in parallel with the input shaft; a first planetary gear set disposed on the first rotation shaft and including first, second and third rotation elements respectively connected to first motor/generator, output gear, and input shaft; a second planetary gear set disposed on the first rotation shaft and including fourth, fifth and sixth rotation elements respectively connected to second motor/generator and input shaft, second rotation element, and transmission housing; transfer gears forming externally-meshed gears; and frictional elements connecting one rotation element of the second planetary gear set to the input shaft, coupling the second planetary gear set, or connecting another rotation element of the second planetary gear set to the transmission housing.

16 Claims, 11 Drawing Sheets

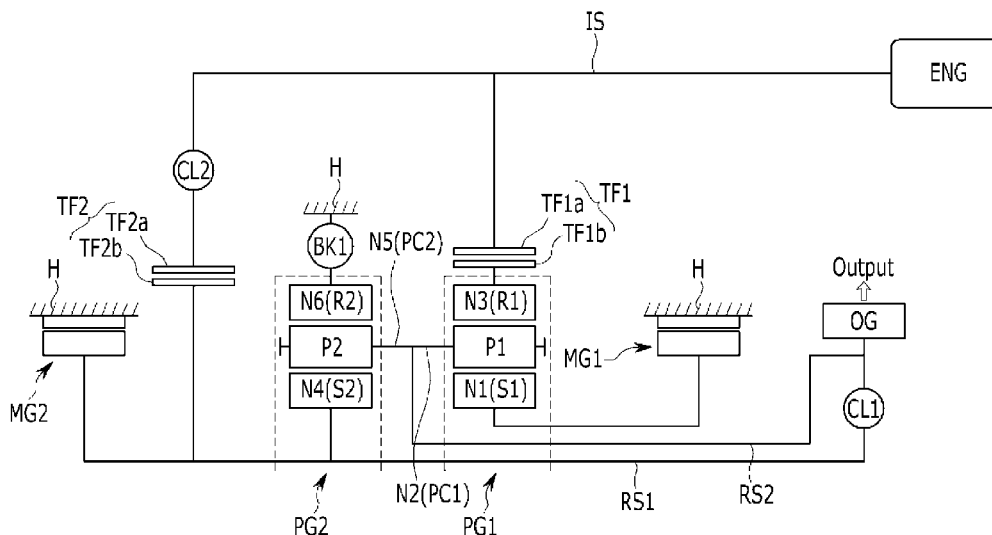


FIG. 1

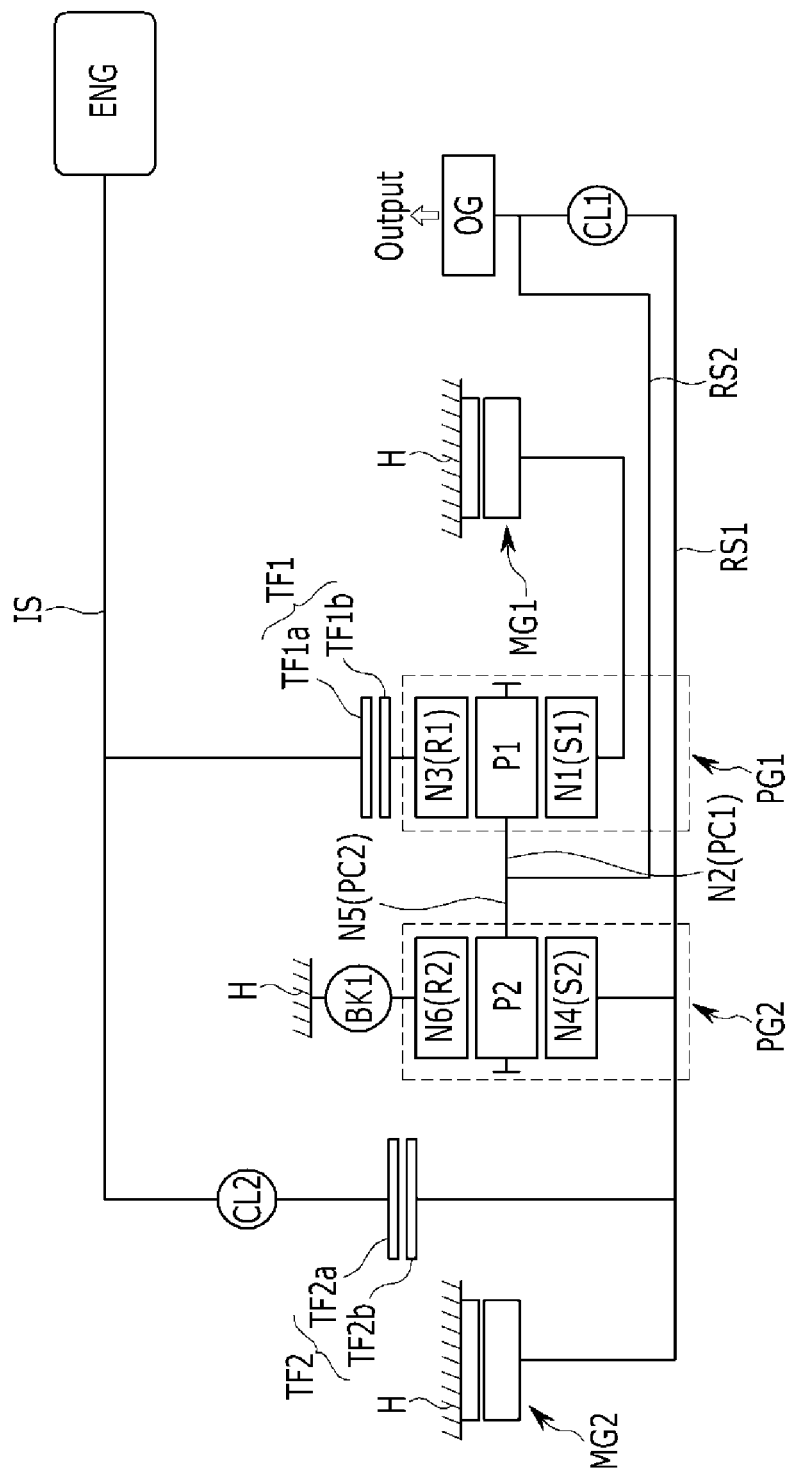


FIG.2

| Mode | Shift-speed | Frictional element | | |
|------------------------------|-----------------|--------------------|-----|-----|
| | | CL1 | CL2 | BK1 |
| First EV mode | 1 ST | | | ● |
| Second EV mode | 2 ND | ● | | |
| First hybrid operating mode | 1 ST | | | ● |
| Second hybrid operating mode | 2 ND | ● | | |
| Third hybrid operating mode | — | | ● | |
| First engine mode | 1 ST | | ● | ● |
| Second engine mode | 2 ND | ● | ● | |

FIG.3

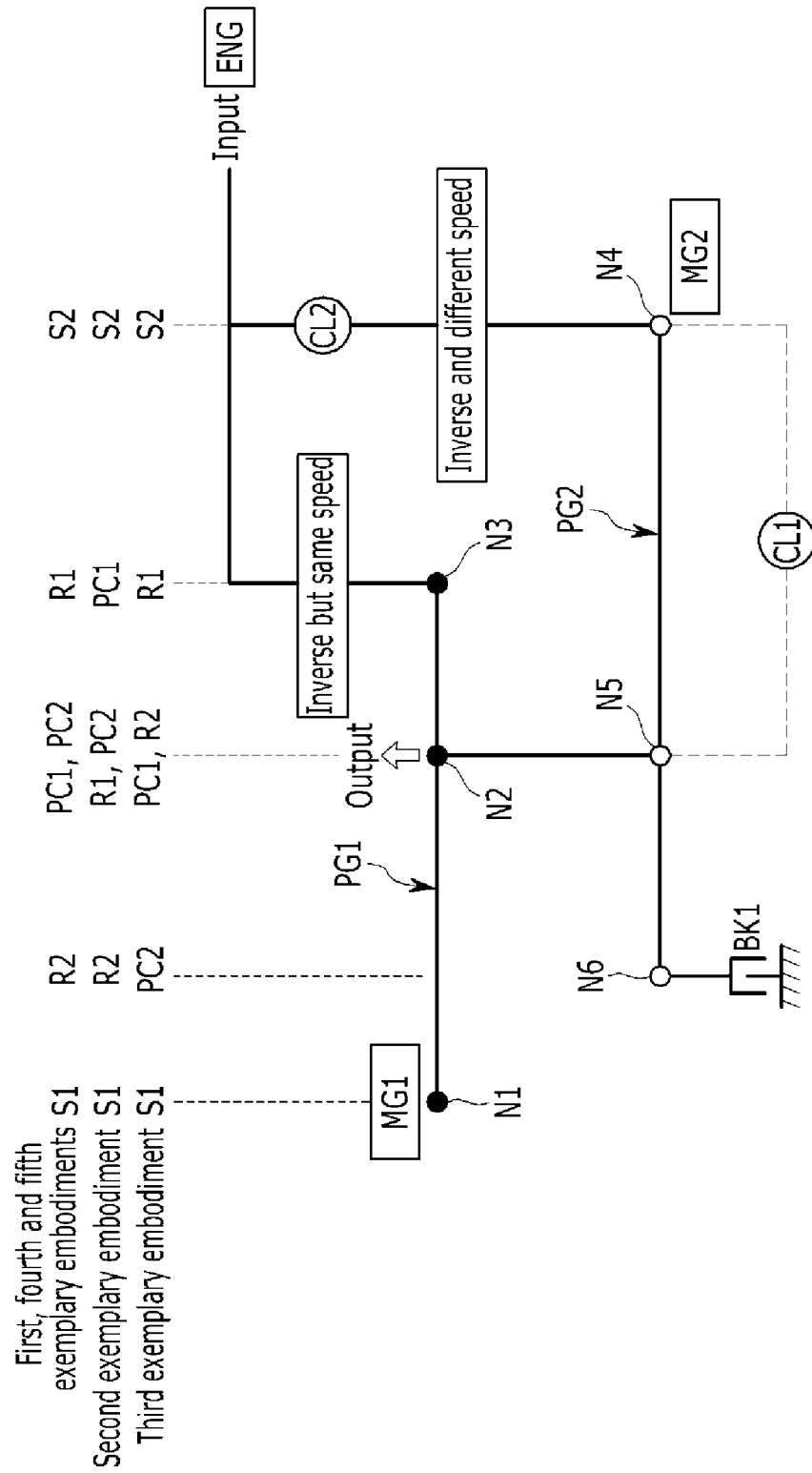


FIG. 4

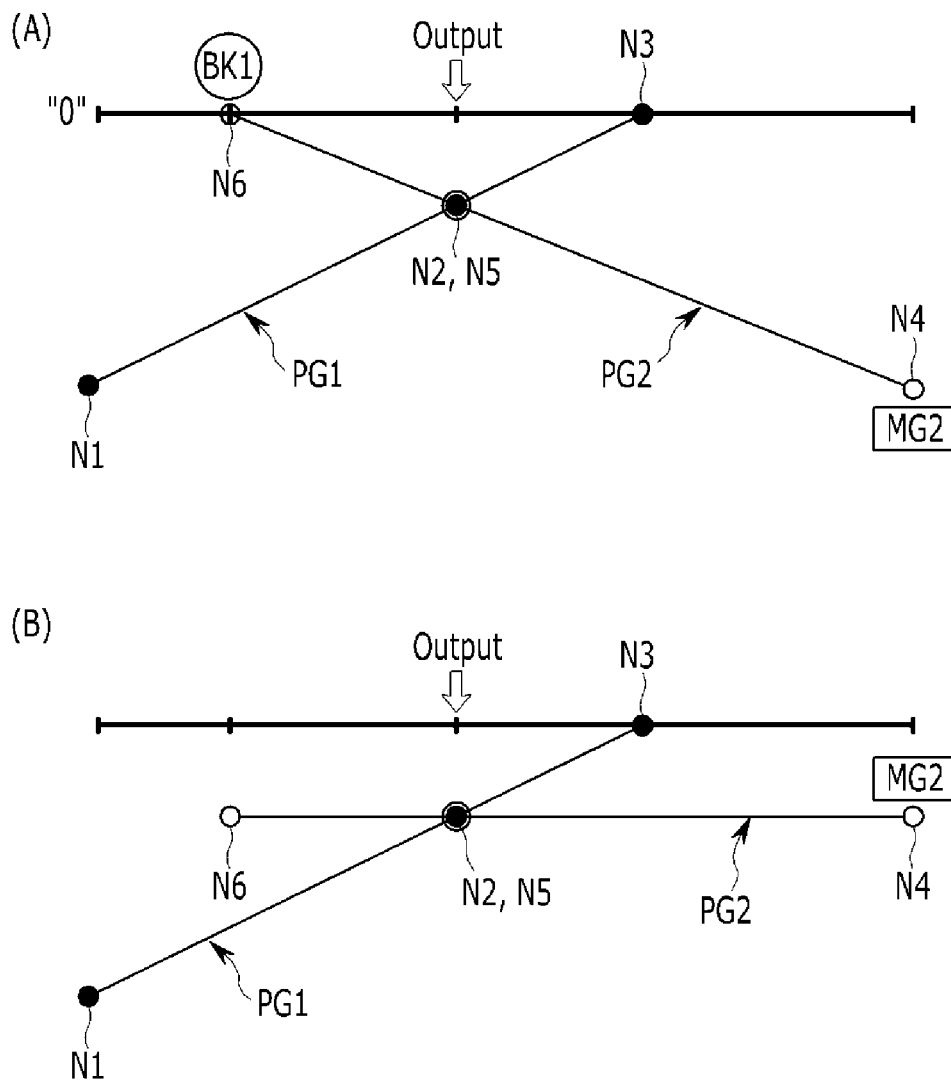


FIG.5

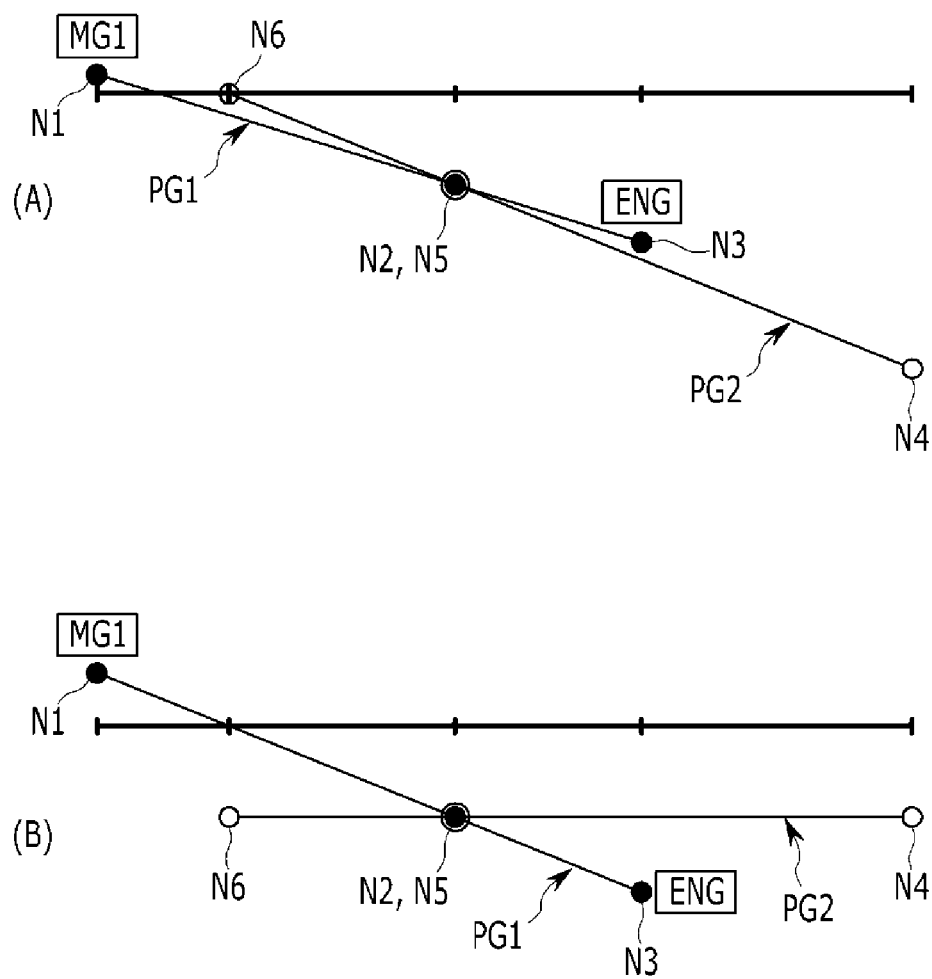


FIG.6

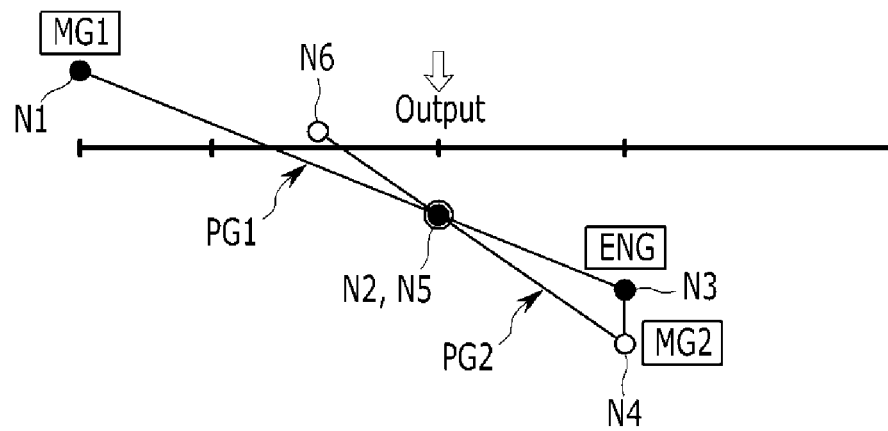


FIG. 7

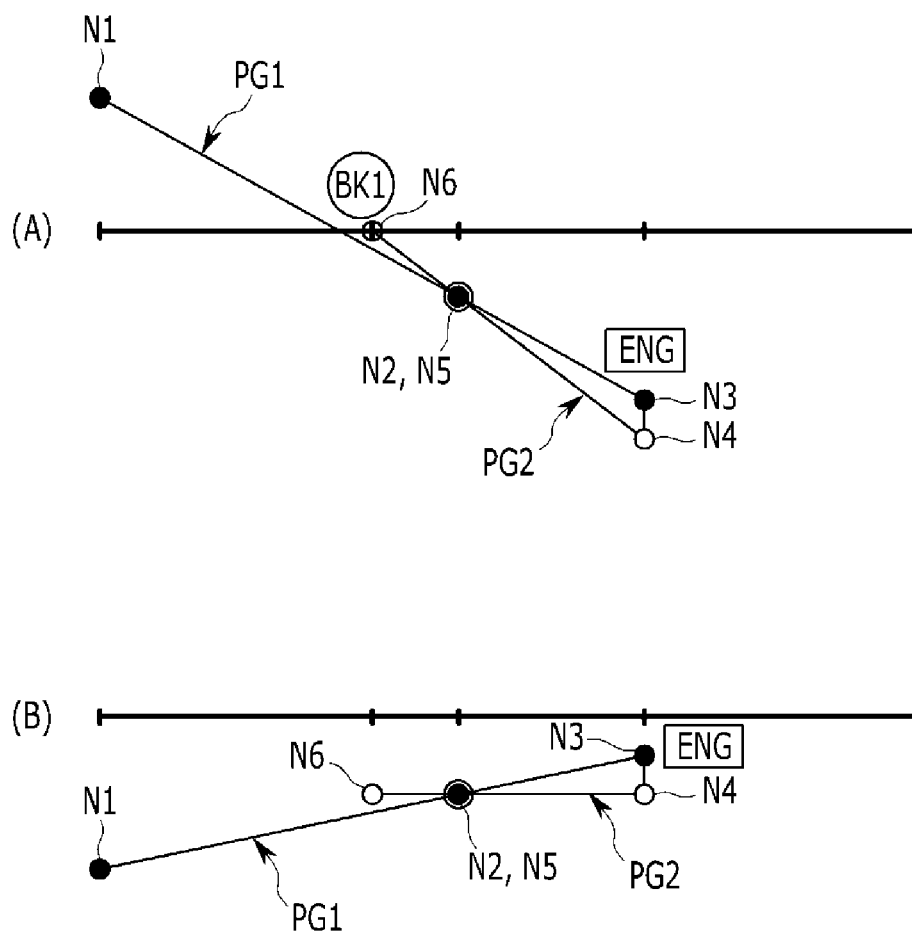


FIG. 8.

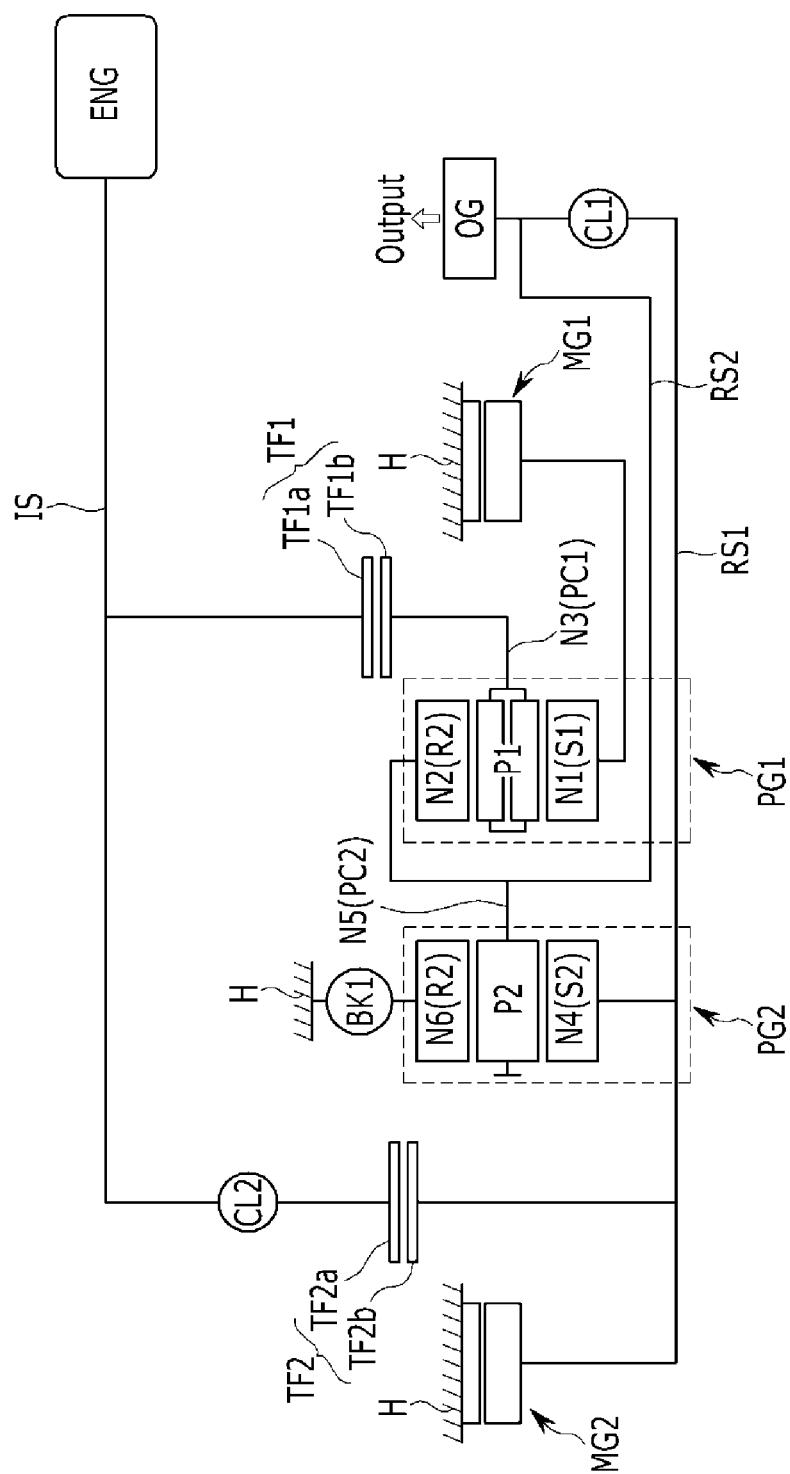


FIG. 9

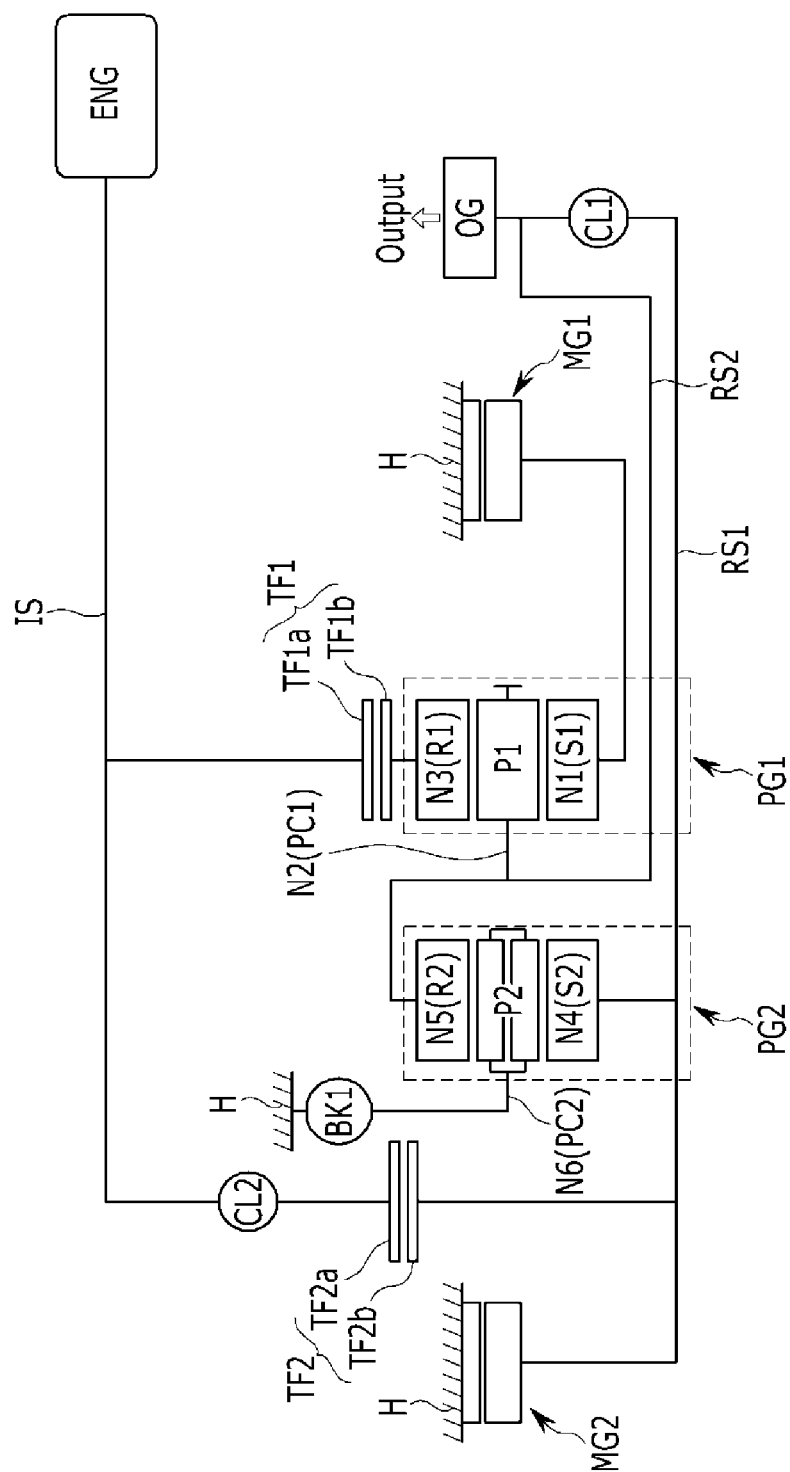


FIG. 10

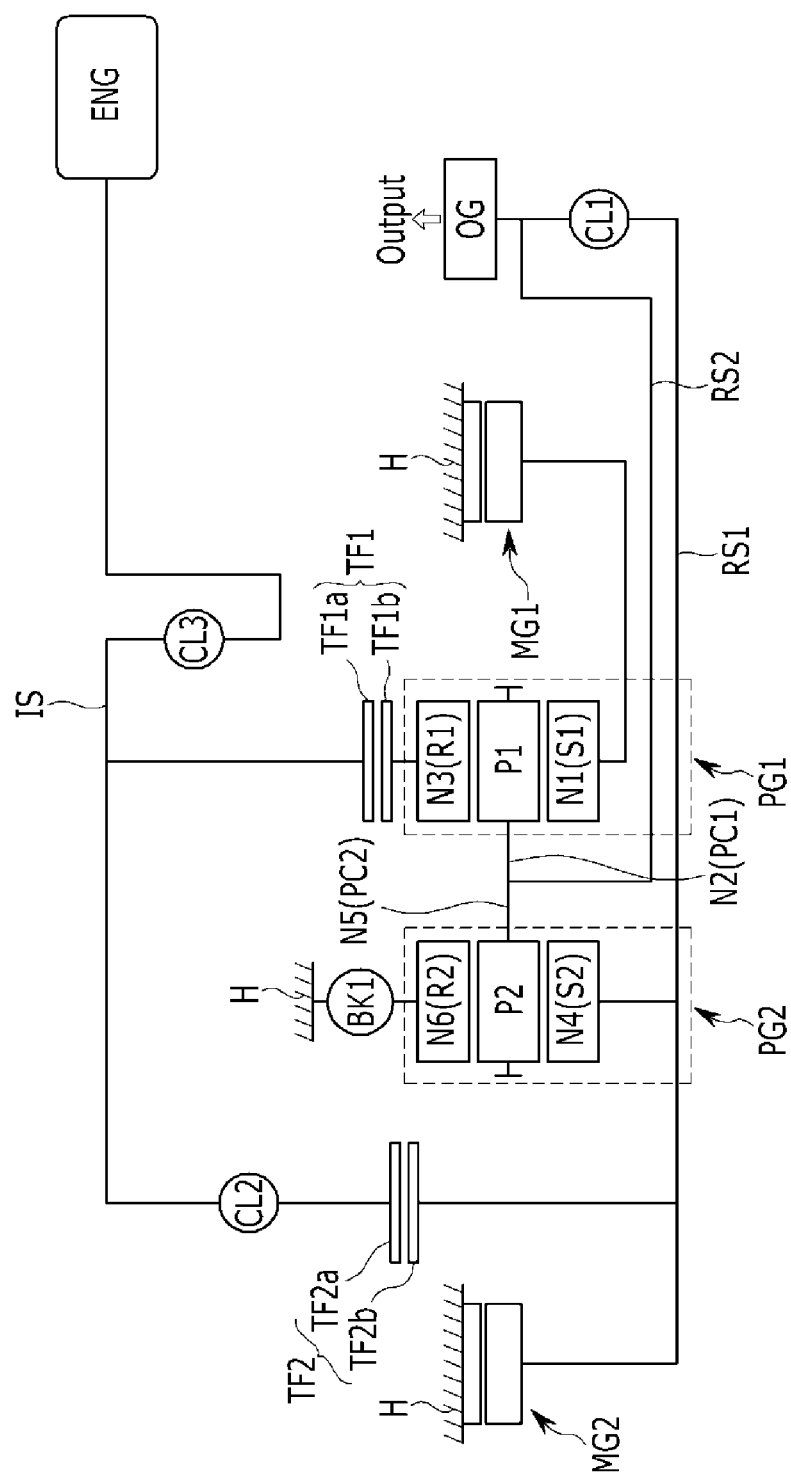
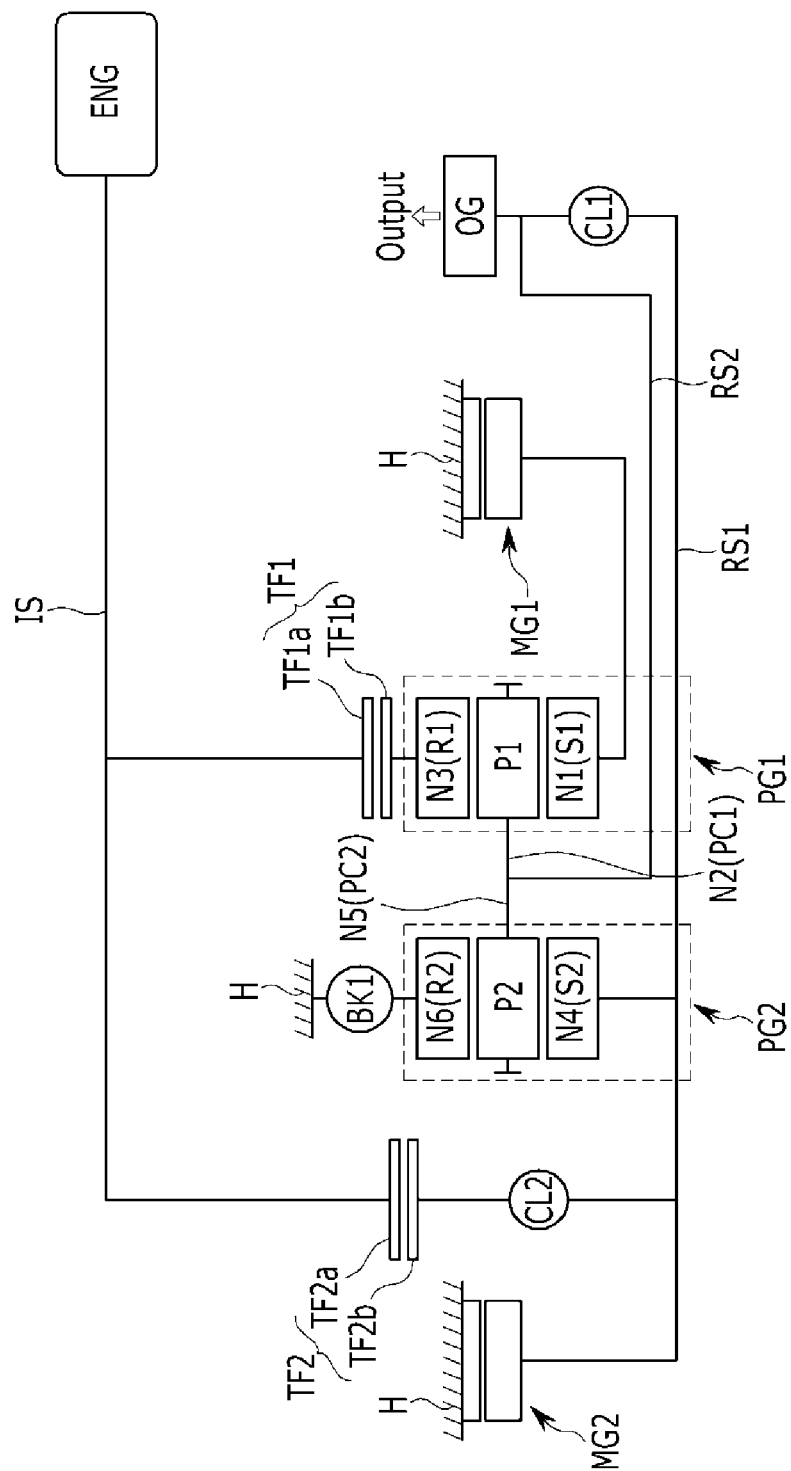


FIG. 11



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POWER TRANSMISSION SYSTEM OF HYBRID ELECTRIC VEHICLE

CROSS-REFERENCE TO RELATED APPLICATION

The present application claims priority of Korean Patent Application Number 10-2013-0076706 filed on Jul. 1, 2013, the entire contents of which application are incorporated herein for all purposes by this reference.

BACKGROUND OF INVENTION

1. Field of Invention

The present invention relates to a power transmission system of a hybrid vehicle. More particularly, the present invention relates to a power transmission system of a hybrid vehicle which minimizes impact due to torque change of a motor/generator when being converted into a hybrid operating mode and reduces electric load and capacity of the motor/generator by giving more importance on mechanical power delivery path when splitting engine power.

2. Description of Related Art

Environmentally-friendly technique of vehicles is very important technique on which survival of future motor industry is dependent. Vehicle makers are focusing on development of environmentally-friendly vehicles so as to meet environment and fuel consumption regulations. Therefore, the vehicle makers have been developing future vehicles such as electric vehicles (EV), hybrid electric vehicles (HEV), and fuel cell electric vehicles (FCEV).

Since the future vehicles have technical restrictions such as weight and cost, the vehicle makers keep observation upon hybrid electric vehicles for meeting exhaust gas regulations and improving fuel consumption performance and are competing desperately to put the hybrid electric vehicles to practical use.

The hybrid electric vehicles are vehicles using more than two power sources, and gasoline engines or diesel engines using fossil fuel and motor/generators driven by electrical energy are mainly used as the power sources of the hybrid electric vehicles. The hybrid electric vehicle uses the motor/generator having relatively better low-speed torque characteristics as a main power source at a low-speed and uses an engine having relatively better high-speed torque characteristics as a main power source at a high-speed. Since the hybrid electric vehicle stops operation of the engine using the fossil fuel and uses the motor/generator at a low-speed region, fuel consumption may be improved and exhaust gas may be reduced.

The power transmission system of a hybrid electric vehicle is classified into a single-mode type and a multi-mode type.

A torque delivery apparatus such as clutches and brakes for shift control is not necessary, but fuel consumption is high due to deterioration of efficiency at a high-speed region and an additional torque multiplication device is required for being applied to a large vehicle according to the single-mode type.

Since the multi-mode type has high efficiency at the high-speed region and is able to multiply torque autonomously, the multi-mode type can be applied to a full size vehicle. Therefore, the multi-mode type instead of the single-mode type is applied as the power transmission system of a hybrid electric vehicle and is also under continuous investigation.

The power transmission system of the multi-mode type includes a plurality of planetary gear sets, a plurality of motor/generators operated as a motor and/or a generator, a plurality of torque delivery apparatus controlling rotation

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elements of the planetary gear sets, and a battery used as a power source of the motor/generators.

The power transmission system of the multi-mode type has different operating mechanisms depend on connections of the planetary gear sets, the motor/generators, and the torque delivery apparatus. In addition, the power transmission system of the multi-mode type has different features such a durability, power delivery efficiency, and size depend on the connections of the planetary gear sets, the motor/generators, and the torque delivery apparatus. Therefore, designs for the connection structure of the power transmission system of a hybrid electric vehicle are also under continuous investigation to achieve robust and compact power transmission system having no power loss.

The information disclosed in this Background section is only for enhancement of understanding of the general background of the invention and should not be taken as an acknowledgement or any form of suggestion that this information forms the prior art already known to a person skilled in the art.

SUMMARY OF INVENTION

The present invention has been made in an effort to provide a power transmission system of a hybrid electric vehicle having advantages of minimizing impact due to torque change of a motor/generator when being converted into a hybrid operating mode and reducing electric load and capacity of the motor/generator by giving more importance on mechanical power delivery path when splitting engine power. In addition, the present invention has been made in an effort to provide a power transmission system of a hybrid electric vehicle having further advantages of providing engine modes where a vehicle runs without consuming electric energy at the motor/generator for enhancement of fuel consumption when high-speed traveling.

A power transmission system of a hybrid electric vehicle according to various aspects of the present invention may include: an input shaft receiving torque of an engine; a first rotation shaft disposed in parallel with the input shaft; a first planetary gear set disposed on the first rotation shaft, and including a first rotation element directly connected to a first motor/generator, a second rotation element connected to an output gear through a second rotation shaft disposed without rotational interference with the first rotation shaft, and a third rotation element connected to the input shaft through a first externally-meshed gear; a second planetary gear set disposed on the first rotation shaft, and including a fourth rotation element connected to a second motor/generator through the first rotation shaft and selectively connected to the input shaft through the first or a second externally-meshed gear or combination thereof, a fifth rotation element connected to the second rotation element, and a sixth rotation element selectively connected to a transmission housing; transfer gears forming the first and second externally-meshed gears; and frictional elements selectively connecting one rotation element of the second planetary gear set to the input shaft, directly coupling the second planetary gear set, or selectively connecting another rotation element of the second planetary gear set to the transmission housing.

In one aspect, the first planetary gear set may be a single pinion planetary gear set, and may include a first sun gear being the first rotation element, a first planet carrier being the second rotation element, and a first ring gear being the third rotation element. In addition, the second planetary gear set may be a single pinion planetary gear set, and may include a second sun gear being the fourth rotation element, a second

planet carrier being the fifth rotation element, and a second ring gear being the sixth rotation element.

In another aspect, the first planetary gear set may be a double pinion planetary gear set, and may include a first sun gear being the first rotation element, a first ring gear being the second rotation element, and a first planet carrier being the third rotation element. In addition, the second planetary gear set may be a single pinion planetary gear set, and may include a second sun gear being the fourth rotation element, a second planet carrier being the fifth rotation element, and a second ring gear being the sixth rotation element.

In yet another aspect, the first planetary gear set may be a single pinion planetary gear set, and may include a first sun gear being the first rotation element, a first planet carrier being the second rotation element, and a first ring gear being the third rotation element. In addition, the second planetary gear set may be a double pinion planetary gear set, and may include a second sun gear being the fourth rotation element, a second ring gear being the fifth rotation element, and a second planet carrier being the sixth rotation element.

In an aspect, the transfer gears may include a first transfer gear connecting the input shaft to the third rotation element and a second transfer gear connecting the input shaft to the fourth rotation element. In an aspect, the frictional elements may include: a first clutch disposed between the first rotation shaft and the second rotation shaft; a second clutch disposed between the input shaft and the second transfer gear; and a first brake disposed between the sixth rotation element and the transmission housing.

In some aspects, the first brake may be operated at a first EV mode, the first clutch may be operated at a second EV mode, the first brake may be operated at a first hybrid operating mode, the first clutch may be operated at a second hybrid operating mode, the second clutch may be operated at a third hybrid operating mode, the second clutch and the first brake may be operated at a first engine mode, and the first clutch and the second clutch may be operated at a second engine mode. In an aspect, a third clutch may be disposed between the engine and the input shaft.

In other aspects, the frictional elements may include a first clutch disposed between the first rotation shaft and the second rotation shaft, a second clutch disposed between the second transfer gear and the first rotation shaft, and a first brake disposed between the sixth rotation element and the transmission housing.

A power transmission system of a hybrid electric vehicle according to various other aspects of the present invention may include: an input shaft receiving torque of an engine; a first rotation shaft disposed in parallel with the input shaft; a first planetary gear set including a first rotation element directly connected to a first motor/generator, a second rotation element connected to an output gear through a second rotation shaft disposed without rotational interference with the first rotation shaft, and a third rotation element connected to the input shaft; a second planetary gear set including a fourth rotation element connected to a second motor/generator and selectively connected to the input shaft, a fifth rotation element connected to the second rotation element, and a sixth rotation element selectively connected to a transmission housing; a first transfer gear connecting the input shaft to the third rotation element; a second transfer gear connecting the input shaft to the fourth rotation element; and frictional elements selectively connecting one rotation element of the second planetary gear set to the input shaft, directly coupling the second planetary gear set, or selectively connecting another rotation element of the second planetary gear set to the transmission housing.

In one aspect, the first planetary gear set may be a single pinion planetary gear set, and may include a first sun gear being the first rotation element, a first planet carrier being the second rotation element, and a first ring gear being the third rotation element. In addition, the second planetary gear set may be a single pinion planetary gear set, and may include a second sun gear being the fourth rotation element, a second planet carrier being the fifth rotation element, and a second ring gear being the sixth rotation element.

In another aspect, the first planetary gear set may be a double pinion planetary gear set, and may include a first sun gear being the first rotation element, a first ring gear being the second rotation element, and a first planet carrier being the third rotation element. In addition, the second planetary gear set may be a single pinion planetary gear set, and may include a second sun gear being the fourth rotation element, a second planet carrier being the fifth rotation element, and a second ring gear being the sixth rotation element.

In still another aspect, the first planetary gear set may be a single pinion planetary gear set, and may include a first sun gear being the first rotation element, a first planet carrier being the second rotation element, and a first ring gear being the third rotation element. In addition, the second planetary gear set may be a double pinion planetary gear set, and may include a second sun gear being the fourth rotation element, a second ring gear being the fifth rotation element, and a second planet carrier being the sixth rotation element.

In an aspect, the frictional elements may include a first clutch disposed between the first rotation shaft and the second rotation shaft, a second clutch disposed between the input shaft and the second transfer gear, and a first brake disposed between the sixth rotation element and the transmission housing.

In some aspects, the first brake may be operated at a first EV mode, the first clutch may be operated at a second EV mode, the first brake may be operated at a first hybrid operating mode, the first clutch may be operated at a second hybrid operating mode, the second clutch may be operated at a third hybrid operating mode, the second clutch and the first brake may be operated at a first engine mode, and the first clutch and the second clutch may be operated at a second engine mode. In an aspect, a third clutch may be disposed between the engine and the input shaft.

In other aspects, the frictional elements may include a first clutch disposed between the first rotation shaft and the second rotation shaft, a second clutch disposed between the second transfer gear and the first rotation shaft, and a first brake disposed between the sixth rotation element and the transmission housing.

The methods and apparatuses of the present invention have other features and advantages which will be apparent from or are set forth in more detail in the accompanying drawings, which are incorporated herein, and the following Detailed Description, which together serve to explain certain principles of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of an exemplary power transmission system according to the present invention.

FIG. 2 is an operational chart of frictional elements at each mode applied to a power transmission system according to the system of FIG. 1.

FIG. 3 is a schematic diagram briefly illustrating connection of rotation elements in a power transmission system according to the system of FIG. 1.

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FIGS. 4(A), 4(B), 5(A), 5(B), 6, 7(A) and 7(B) are respective drawings for explaining operation of a power transmission system according to the system of FIG. 1 at each mode.

FIG. 8 is a schematic diagram of an exemplary power transmission system according to the present invention.

FIG. 9 is a schematic diagram of an exemplary power transmission system according to the present invention.

FIG. 10 is a schematic diagram of an exemplary power transmission system according to the present invention.

FIG. 11 is a schematic diagram of an exemplary power transmission system according to the present invention.

DETAILED DESCRIPTION

Reference will now be made in detail to various embodiments of the present invention(s), examples of which are illustrated in the accompanying drawings and described below. While the invention(s) will be described in conjunction with exemplary embodiments, it will be understood that present description is not intended to limit the invention(s) to those exemplary embodiments. On the contrary, the invention(s) is/are intended to cover not only the exemplary embodiments, but also various alternatives, modifications, equivalents and other embodiments, which may be included within the spirit and scope of the invention as defined by the appended claims.

Description of components that are not necessary for explaining the exemplary embodiments will be omitted, and the same constituent elements are denoted by the same reference numerals in this specification. In the detailed description, ordinal numbers are used for distinguishing constituent elements having the same terms, and have no specific meanings.

FIG. 1 is a schematic diagram of a power transmission system according to various embodiments of the present invention. Referring to FIG. 1, a power transmission system of a hybrid electric vehicle changes torque of an engine ENG transmitted through an input shaft IS according to running state of a vehicle, and outputs the changed torque through an output gear OG. The power transmission system includes first and second planetary gear sets PG1 and PG2, first and second motor/generators MG1 and MG2, and frictional elements including first and second clutches CL1 and CL2 and a first brake BK1.

The first planetary gear set PG1 includes first, second, and third rotation elements N1, N2, and N3, and the second planetary gear set PG2 includes fourth, fifth, and sixth rotation elements N4, N5, and N6. The first planetary gear set PG1 and the second planetary gear set PG2 are disposed on a first rotation shaft RS1 disposed in parallel or substantially in parallel with the input shaft IS.

The third rotation element N3 is connected to the input shaft IS through an externally-meshed gear and is selectively connected to the fourth rotation element N4 through an externally-meshed gear. The second rotation element N2 and the fifth rotation element N5 are connected to the output gear OG and are selectively connected to the fourth rotation element N4 in a state of being directly connected to each other.

The first rotation element N1 is directly connected to the first motor/generator MG1, the third rotation element N3 is connected to the input shaft IS through a first transfer drive gear TF1 that is an externally-meshed gear, and the third rotation element N3 is selectively connected to the fourth rotation element N4 through the first transfer drive gear TF1 and a second transfer gear TF2. That is, the third rotation element N3 is selectively connected to the second transfer gear TF2.

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The third rotation element N3 and the second transfer gear TF2 can be connected through an additional rotation member, but it is exemplified in the present exemplary embodiments that the input shaft IS connected to the third rotation element N3 is selectively connected to the second transfer gear TF2.

In addition, the second rotation element N2 and the fifth rotation element N5 are connected to the output gear OG through a second rotation shaft RS2 that is disposed at an external circumference of the first rotation shaft RS1 without rotational interference with the first rotation shaft RS1, and the first rotation shaft RS1 and the second rotation shaft RS2 are selectively connected. Therefore, the second rotation element N2 and the fifth rotation element N5 can be selectively connected to the fourth rotation element N4 connected to the first rotation shaft RS1.

The first and second transfer gears TF1 and TF2 respectively have first and second transfer drive gears TF1a and TF2a and first and second transfer driven gear TF1b and TF2b externally meshed with each other. The first transfer drive gear TF1a of the first transfer gear TF1 is connected to the input shaft IS, and the first transfer driven gear TF1b externally meshed with the first transfer drive gear TF1a is connected to the third rotation element N3. The second transfer drive gear TF2a of the second transfer gear TF2 is selectively connected to the input shaft IS, and the second transfer driven gear TF2b externally meshed with the second transfer drive gear TF2a is connected to the fourth rotation element N4. In addition, gear ratios of the first and second transfer gears TF1 and TF2 can be set according to target speed ratios.

The first motor/generator MG1 and the second motor/generator MG2 are independent power sources and are operated as a motor and a generator. The first motor/generator MG1 is operated as the motor that supplies torque to the first rotation element N1 of the first planetary gear set PG1 or is operated as the generator that generates electricity by torque of the first rotation element N1. The second motor/generator MG2 is operated as the motor that supplies torque to the fourth rotation element N4 of the second planetary gear set PG2 or is operated as the generator that generates electricity by torque of the fourth rotation element N4.

For this purpose, the first motor/generator MG1 and the second motor/generator MG2 as well as the first and second planetary gear sets PG1 and PG2 are disposed on the first rotation shaft RS1, a stator of the first motor/generator MG1 and a stator of the second motor/generator MG2 are fixed to the transmission housing H, and a rotor of the first motor/generator MG1 and a rotor of the second motor/generator MG2 are connected respectively to the first rotation element N1 of the first planetary gear set PG1 and the fourth rotation element N4 of the second planetary gear set PG2.

The first clutch CL1 is operated as a selective direct-coupling means. The first clutch CL1 selectively connects the fourth rotation element N4 (and first rotation shaft RS1) to the fifth rotation element N5 (and second rotation shaft RS2). The second clutch CL2 and the first brake BK1 are operated as selective connecting means. The second clutch CL2 selectively connects the third rotation element N3 of the first planetary gear set PG1 (and input shaft IS) to the fourth rotation element N4 of the second planetary gear set PG2 (and first rotation shaft RS1), and the first brake BK1 selectively connects the sixth rotation element N6 of the second planetary gear set PG2 to the transmission housing H.

The first and second clutches CL1 and CL2 are frictional elements selectively connecting a rotation element with another rotation element, and the first brake BK1 is a frictional element selectively connecting a rotation element with a fixed element (i.e., transmission housing). The first and

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second clutches CL1 and CL2 and the brake BK may be conventional multi-plate friction elements of wet type that are operated by hydraulic pressure.

The power transmission system of a hybrid electric vehicle of FIG. 1 will be described in further detail.

The first planetary gear set PG1 is a single pinion planetary gear set, and includes the first rotation element N1 being a first sun gear S1, the second rotation element N2 being a first planet carrier PC1 rotatably supporting a first pinion P1 externally meshed with the first sun gear S1, and the third rotation element N3 being a first ring gear R1 internally meshed with the first pinion P1.

The second planetary gear set PG2 is a single pinion planetary gear set, and includes the fourth rotation element N4 being a second sun gear S2, the fifth rotation element N5 being a second planet carrier PC2 rotatably supporting a second pinion P2 externally meshed with the second sun gear S2, and the sixth rotation element N6 being a second ring gear R2 internally meshed with the second pinion P2.

The input shaft IS is connected to the first ring gear R1 through the externally-meshed gear and is selectively connected to the second sun gear S2 through the externally-meshed gear. The first planet carrier PC1 and the second planet carrier PC2 is connected to the output gear OG and is selectively connected to the second sun gear S2 in a state of being directly connected to each other.

The first ring gear R1 is connected to the input shaft IS through the first transfer gear TF1 that is the externally-meshed gear and is selectively connected to the second sun gear S2 through the first and second transfer gears TF1 and TF2. That is, the first ring gear R1 and the second transfer gear TF2 are selectively connected. The first ring gear R1 and the second transfer gear TF2 can be connected through an additional rotation member, but it is exemplified in this specification that the input shaft IS connected to the first ring gear R1 is connected to the second transfer gear TF2.

In addition, the first planet carrier PC1 and the second planet carrier PC2 are connected to the output gear OG through the second rotation shaft RS2 that is disposed at the external circumference of the first rotation shaft RS1 without rotational interference therewith, and the first rotation shaft RS1 and the second rotation shaft RS1 are selectively connected. Therefore, the first and second planet carriers PC1 and PC2 can be selectively connected to the second sun gear S2 connected to the first rotation shaft RS1.

The first and second transfer gears TF1 and TF2 respectively have the first and second transfer drive gears TF1a and TF2a and the first and second transfer driven gears TF1b and TF2b externally meshed with each other. The first and second transfer drive gears TF1a and TF2a are connected to the input shaft IS, and the first and second transfer driven gears TF1b and TF2b externally meshed with the first and second transfer drive gears TF1a and TF2a are connected to the first ring gear R1 and the second sun gear S2, respectively.

The first motor/generator MG1 is operated as the motor that supplies torque to the first sun gear S1 or is operated as the generator that generates electricity by torque of the first sun gear S1. The second motor/generator MG2 is operated as the motor that supplies torque to the second sun gear S2 or is operated as the generator that generates electricity by torque of the second sun gear S2.

The first clutch CL1 selectively connects the second sun gear S2 with the second planet carrier PC2 so as to directly couple the second planetary gear set PG2 selectively. That is, The first clutch CL1 selectively connects the first rotation shaft RS1 and the second rotation shaft RS2. The second clutch CL2 selectively connects the first ring gear R1 of the

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first planetary gear set PG1 with the second sun gear S2 of the second planetary gear set PG2, and the first brake BK1 selectively connects the second ring gear R2 of the second planetary gear set PG2 with the transmission housing H.

FIG. 2 is an operational chart of frictional elements at each mode applied to a power transmission system shown in FIG. 1. Referring to FIG. 2, a first EV (Electric Vehicle) mode is achieved by operating the first brake BK1. A second EV mode is achieved by operating the first clutch CL1. A first hybrid operating mode is achieved by operating the first brake BK1. A second hybrid operating mode is achieved by operating the first clutch CL1. A third hybrid operating mode is achieved by operating the second clutch CL2. A first engine mode is achieved by operating the second clutch CL2 and the first brake BK1. A second engine mode is achieved by operating the first clutch CL1 and the second clutch CL2.

As described above, the power transmission system according to various embodiments of the present invention can realize two EV modes, three hybrid operating modes, and two engine modes.

FIG. 3 is a schematic diagram briefly illustrating connection of rotation elements in a power transmission system illustrated in FIG. 1. Referring to FIG. 3, the second rotation element N2 and the fifth rotation element N5 are directly connected and the fourth rotation element N4 and the fifth rotation element N5 are selectively connected through the first clutch CL1 in the power transmission system according to the system of FIG. 1.

In addition, the first rotation element N1 is connected to the first motor/generator MG1, the third rotation element N3 is connected to the input shaft IS to which the torque of the engine ENG is input through the first transfer gear TF1, and the fourth rotation element N4 is connected to the second motor/generator MG2 and is selectively connected to the input shaft IS through the second transfer gear TF2 and the second clutch CL2. In addition, the sixth rotation element N6 is selectively connected to the transmission housing H through the first brake BK1.

FIG. 4 to FIG. 7 are drawings for explaining operation of a power transmission system according to the system of FIG. 1 at each mode. FIG. 4 to FIG. 7 illustrate change of input rotation speed assuming that output rotation speed is constant or substantially constant.

First EV Mode

FIG. 4A is a drawing for explaining operation of the power transmission system according to the system of FIG. 1 at the first EV mode. The EV mode is a mode where power of a battery is supplied to a motor/generator in a stopped state of an engine such that a vehicle is driven by power of the motor/generator. Since the engine is stopped, fuel economy may be enhanced, and the vehicle can move rearward without an additional reverse speed device at the EV mode. The EV mode is utilized when the vehicle is started in a stopped state or the vehicle runs with a low speed. A reduced gear ratio where the power source rotates faster than an output member is required for assisting hill-start or quick acceleration.

Under such conditions, the sixth rotation element N6 is operated as a fixed element by operation of the first brake BK1, and the second motor/generator MG2 is operated so as to input torque of the second motor/generator MG2 to the fourth rotation element N4 at the first EV mode. Therefore, the torque of the second motor/generator MG2 is changed according to the gear ratio of the second planetary gear set PG2 and the changed torque is output

At this time, the first planetary gear set PG1 is not involved in a shift. However, the third rotation element N3 is stopped together with the engine and the second rotation element N2

is directly connected to the fifth rotation element N5. Therefore, the first and second rotation elements N1 and N2 are idling.

Second EV Mode

FIG. 4B is a drawing for explaining operation of the power transmission system according to the system of FIG. 1 at the second EV mode. Efficiency of the motor/generator changes according to rotation speed and torque thereof. This means that a conversion ratio of electrical energy into mechanical energy is different according to the rotation speed and the torque of the motor/generator even though the same amount of current is supplied.

Current of the battery used at EV mode is generated by burning fuel in the engine or being accumulated by regenerative braking, but how to use the accumulated energy efficiently affects on enhancement of fuel economy directly. For this reason, a transmission realizing more than two shift-speeds is increasingly mounted on the electric vehicle, and it is advantageous that the hybrid vehicle realizes the EV mode having more than two shift-speeds. Therefore, the exemplary embodiments of the present invention can realize two EV modes.

Shifting processes to the second EV mode are as follows. If vehicle speed increases during the vehicle drives at the first EV mode, efficiency of the second motor/generator MG2 is deteriorated. At this time, if the first brake BK1 is released and the first clutch CL1 is operated at a point where the efficiency of the second motor/generator MG2 is bad, the second EV mode is achieved.

In this case, since the first clutch CL1 that is the direct-coupling device of the second planetary gear set PG2 is operated, the second planetary gear set PG2 becomes a direct-coupling state. Therefore, all the rotation elements N4, N5, and N6 of the second planetary gear set PG2 rotate with the same speed and the driving torque is output through the fifth rotation element N5. At this time, the first planetary gear set PG1 is not involved in a shift. However, the third rotation element N3 is stopped together with the engine, and the first and second rotation elements N1 and N2 are idling.

First Hybrid Operating Mode

FIG. 5A is a drawing for explaining operation of the power transmission system according to the system of FIG. 1 at the first hybrid operating mode. The torque of the engine is delivered to the output member through mechanical path and electrical path at the first hybrid operating mode, and such split of the engine torque is done by the planetary gear set. Since the engine and the motor/generator connected to the planetary gear set can control their rotation speeds regardless of the vehicle speed, the power transmission system at the first hybrid operating mode is operated as an electric continuously variable transmission.

The speed and the torque of the engine are fixed at given vehicle speed in a conventional transmission, but the speed and the torque of the engine can be changed freely at the given vehicle speed in the electric continuously variable transmission. Therefore, driving efficiency of the engine may be maximized and fuel economy may be enhanced.

Shifting processes to the first hybrid operating mode are as follows. The second rotation element N2 of the first planetary gear set PG1 as well as the fifth rotation element N5 is connected to the output gear OG, but the first and third rotation elements N1 and N3 can rotate freely at the first EV mode (referring to FIG. 4A).

If the engine ENG is started using the first motor generator MG1 at this state, speeds of the engine ENG and the first motor/generator MG1 can be controlled regardless of the vehicle speed. Therefore, if the engine ENG and the first

motor/generator MG1 are controlled, the torque of the engine and the torque of the first motor/generator MG1 are summed up and the summed torque is delivered to the fifth rotation element N5 that is the output element. Therefore, high driving torque may be generated.

At this time, the first motor/generator MG1 is operated as the generator if rotating positively, and the first motor/generator MG1 is operated as the motor if rotating negatively (at this time, the rotation speed of the engine ENG decreases). In addition, the sixth rotation element N6 is operated as the fixed element by operation of the first brake BK1, the driving torque is output through the fifth rotation element N5, and the fourth rotation element N4 is idling in the second planetary gear set PG2. Since the engine ENG and the first motor/generator MG1 can be controlled independently at the first hybrid operating mode, fuel economy and driving performance may be greatly enhanced.

Second Hybrid Operating Mode

FIG. 5B is a drawing for explaining operation of the power transmission system according to the system of FIG. 1 at the second hybrid operating mode. If the vehicle speed increased during the vehicle runs at the first hybrid operating mode, the first brake BK1 is released and the first clutch CL1 is operated so as to lower rotation speeds of all the rotation elements of the first planetary gear set PG1. Accordingly, the second hybrid operating mode begins.

Since the first clutch CL1 that is the direct-coupling device of the second planetary gear set PG2 is operated, the second planetary gear set PG2 becomes a direct-coupling state. Therefore, all the rotation elements N4, N5, and N6 of the second planetary gear set PG2 rotate with the same speed.

At this time, the second rotation element N2 of the first planetary gear set PG1 as well as the second planetary gear set PG2 is restricted by the output gear OG, but the first and third rotation elements N1 and N3 can rotate freely. Therefore, if the engine ENG and the first motor/generator MG1 are controlled, speeds of the engine ENG and the first motor/generator MG1 can be controlled regardless of the vehicle speed. Since the engine ENG and the first motor/generator MG1 can be controlled independently at the second hybrid operating mode, the same as at the first hybrid operating mode, fuel economy and driving performance may be greatly enhanced.

Third Hybrid Operating Mode

FIG. 6 is a drawing for explaining operation of the power transmission system according to the system of FIG. 1 at the third hybrid operating mode. Since the rotation speed of the motor/generator connected to the output element is restricted to the vehicle speed, the motor/generator cannot be operated efficiently and capacity of the motor/generator is hard to be reduced at the third hybrid operating mode. Particularly, if the rotation speed of the motor/generator restricted to the vehicle speed is high due to high vehicle speed, efficiency of the motor/generator may be deteriorated and fuel economy may be hard to be optimized.

Under such conditions, one rotation element of the first planetary gear set PG1 one rotation element of the second planetary gear set PG2 connected to the engine ENG are coupled to another rotation element of the first planetary gear set PG1 and another rotation element of the second planetary gear set PG2 connected to the output gear OG so that the rotation speed of the engine ENG and the rotation speeds of two motor/generators MG1 and MG2 are controlled regardless the vehicle speed. Thereby, the power transmission system may be operated as a continuously variable transmission and may enhance fuel economy.

If the second clutch CL2 is operated, the rotation speed of the third rotation element N3 and the rotation speed of the

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fourth rotation element N4 are correlated by a predetermined gear ratio (the gear ratios of the first transfer gear and the second transfer gear), and the third rotation element N3 and the fourth rotation element N4 rotate in the same direction.

In addition, since the second rotation element N2 and the fifth rotation element N5 are connected to the output gear OG, the second rotation element N2 and the fifth rotation element N5 rotate with the same speed. Since the rotation elements of the first and second planetary gear sets PG1 and PG2 are restricted by predetermined gear ratios, the speeds and the torques of the rotation elements are restricted to each other. In addition, since electrical energy of the first and second motor/generators MG1 and MG2 should be balanced, the speeds and the torques of all the rotation elements of the first and second planetary gear sets PG1 and PG2 are correlated to each other and the power transmission system operates as the electric continuously variable transmission at the third hybrid operating mode.

The first hybrid operating mode and the second hybrid operating mode can be converted into the third hybrid operating mode. That is, if the first hybrid operating mode and the second hybrid operating mode are converted into the third hybrid operating mode, the second clutch CL2 is operated. After that, the engine ENG and the second motor/generator MG2 that can be independently controlled at the first and second hybrid operating modes are synchronized and the first brake BK1 or the first clutch CL1 is released. Therefore, conversion to the third hybrid operating mode can be done smoothly.

That is, when the first hybrid operating mode is converted into the third hybrid operating mode, the engine ENG and the second motor/generator MG2 are synchronized by operating the second clutch CL2 and the first brake BK1 is released. When the second hybrid operating mode is converted into the third hybrid operating mode, the engine ENG and the second motor/generator MG2 are synchronized by operating the second clutch CL2 and the first clutch CL1 is released.

When converting from the first hybrid operating mode or the second hybrid operating mode to the third hybrid operating mode, direction of torque of the first and second motor/generators MG1 and MG2 does not change. Therefore, impact due to mode conversion does not occur.

First Engine Mode

FIG. 7A is a drawing for explaining operation of the power transmission system according to the system of FIG. 1 at the first engine mode. Important technique in the hybrid vehicle for enhancing fuel economy is recovery and reuse of brake energy and control of driving point of the engine.

In addition, controlling of the driving point of the engine accompanies conversion of mechanical energy of the engine into electric energy of the motor/generator and conversion of the electric energy of the motor/generator back into mechanical energy at the motor/generator. During energy conversion, not all input energy is output and energy loss occurs. Since fuel economy at the engine mode where the vehicle is driven only by the engine may be superior to that at the hybrid mode at any driving condition, the exemplary embodiments of the present invention provide two engine modes.

That is, the second clutch CL2 and the first brake BK1 are engaged at the first engine mode. In this case, the sixth rotation element N6 is operated as the fixed element, and the rotation speed of the engine ENG is changed according to the gear ratio of the second transfer gear TF2 and is then transmitted to the fourth rotation element N4. Therefore, reduced speed ratio is generated. At this time, since the first and second motor/generators MG1 and MG2 do not need to pro-

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vide torque, the first engine mode at which the vehicle is driven only by the engine ENG is achieved.

Second Engine Mode

FIG. 7B is a drawing for explaining operation of the power transmission system according to the system of FIG. 1 at the second engine mode. If the vehicle speed increases during the vehicle runs at the first engine mode, the first brake BK1 is released and the first clutch CL1 is operated.

In this case, all the rotation elements N4, N5, and N6 of the second planetary gear set PG2 rotate with the same speed by operation of the first and second clutches CL1 and CL2. In addition, since the rotation speed of the third rotation element N3 is slower than the rotation speed of the fourth rotation element N4, the fifth rotation element N5 is faster than the engine ENG. Since the first and second motor/generators MG1 and MG2 need not to provide torque at this time, the second engine mode at which the vehicle is driven only by the torque of the engine ENG is achieved.

According to the system of FIG. 1, two EV modes, three hybrid operating modes, and two engine modes can be achieved by combining two planetary gear sets PG1 and PG2, three frictional elements CL1, CL2, and BK1, and two motor/generators MG1 and MG2.

In addition, the electric load may be reduced and the maximum power of the engine may be used by giving more importance on mechanical power delivery path when splitting the engine power. Further, the number of mode conversions may be decreased when starting, and change in rotation speed of all the rotation elements may be minimized when converting modes. Since sufficient power performance is provided in Wide Open Throttle (WOT) start, conversion to the engine mode is suppressed and maximum power of the engine can be used in conversion among the first, second, and third hybrid operating modes.

In addition, the second clutch CL2 is disposed between the third rotation element N3 of the first planetary gear set PG1 and the fourth rotation element N4 of the second planetary gear set PG2 so as to freely perform a mode changed from the first hybrid operating mode or the second hybrid operating mode into the third hybrid operating mode according to the system of FIG. 1. If the second clutch CL2 is operated, the engine ENG and the second motor/generator MG2 that can be independently controlled at the first and second hybrid operating modes are synchronized and conversion to the third hybrid operating mode is then achieved. Therefore, mode conversion can be achieved smoothly. Therefore, impact due to engagement of the second clutch CL2 may be suppressed and direction of torque of the first motor/generator MG1 and the second motor/generator MG2 is maintained before or after mode conversion. Therefore, controllability may be excellent.

After mode conversion is achieved, the engine is operated at its maximum power point at the third hybrid operating mode, and the rotation speed of the second motor/generator MG2 decreases as the vehicle speed increases. Therefore, the vehicle can be driven within a drive limit range of the motor. Since the engine mode is provided, the vehicle can run with high speed without electric load of the first and second motor/generators MG1 and MG2. Therefore, fuel economy may be improved.

FIG. 8 is a schematic diagram of a power transmission system according to various embodiments of the present invention. Referring to FIG. 8, unlike in the system of FIG. 1 where the first planetary gear set PG1 is a single pinion planetary gear set, the first planetary gear set PG1 is a double pinion planetary gear set in the system of FIG. 8.

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Therefore, the first sun gear S1 is the first rotation element N1, the first ring gear R1 is the second rotation element N2, and the first planet carrier PC1 is the third rotation element N3. Since functions of the system of FIG. 8 are the same as or similar to those of the system of FIG. 1 except the rotation elements consisting of the second and third rotation elements N2 and N3, detailed description thereof will be omitted.

FIG. 9 is a schematic diagram of a power transmission system according to various embodiments of the present invention. Referring to FIG. 9, unlike in the system of FIG. 1 where the second planetary gear set PG2 is a single pinion planetary gear set, the second planetary gear set PG2 is a double pinion planetary gear set in the system of FIG. 9.

Therefore, the second sun gear S2 is the fourth rotation element N4, the second ring gear R2 is the fifth rotation element N5, and the second planet carrier PC2 is the sixth rotation element N6. Since functions of the system of FIG. 8 are the same as or similar to those of the system of FIG. 1 except the rotation elements consisting of the fifth and sixth rotation elements N5 and N6, detailed description thereof will be omitted.

FIG. 10 is a schematic diagram of a power transmission system according to various embodiments of the present invention. Referring to FIG. 10, unlike in the system of FIG. 1 where a clutch that is selective power delivery means is not disposed between the engine ENG and the third rotation element N3, a third clutch CL3 that is selective power delivery means is disposed between the engine ENG and the third rotation element N3 in the system of FIG. 10.

Therefore, the third clutch CL3 is operated at a mode where the torque of the engine ENG is demanded, the torque of the engine ENG is transmitted to the third rotation element N3 of the first planetary gear set PG1. Since functions of the system of FIG. 9 are the same as or similar to those of the system of FIG. 1 except whether the third clutch CL3 exists or not, detailed description thereof will be omitted.

FIG. 11 is a schematic diagram of a power transmission system according to various embodiments of the present invention. Referring to FIG. 11, unlike in the system of FIG. 1 where the second clutch CL2 is disposed between the input shaft IS and the second transfer gear TF2, the second clutch CL2 is disposed between the second transfer gear TF2 and the first rotation shaft RS1 in the system of FIG. 11. Since functions of the system of FIG. 11 are the same as or similar to those of the system of FIG. 1 except the position of the second clutch CL2, detailed description thereof will be omitted.

According to various exemplary embodiments of the present invention, the electric load may be reduced and the maximum power of the engine may be used by giving more importance on mechanical power delivery path when splitting the engine power. Further, the number of mode conversions may be decreased when starting, and change in rotation speed of all the rotation elements may be minimized when converting modes. Since sufficient power performance is provided in WOT (Wide Open Throttle) start, conversion to the engine mode is suppressed and maximum power of the engine can be used in conversion between the hybrid input split mode and the compound split mode.

In addition, the second clutch is disposed between the third rotation element of the first planetary gear set and the fourth rotation element of the second planetary gear set so as to freely perform a mode changed from the first hybrid operating mode or the second hybrid operating mode into the third hybrid operating mode according to the exemplary embodiments of the present invention. If the second clutch is operated, the engine and the second motor/generator that can be independently controlled at the first and second hybrid oper-

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ating modes are synchronized and conversion to the third hybrid operating mode is then achieved. Therefore, mode conversion can be achieved smoothly. Therefore, impact due to engagement of the second clutch may be suppressed and direction of torque of the first motor/generator and the second motor/generator is maintained before or after mode conversion. Therefore, controllability may be excellent.

After mode conversion is achieved, the engine is operated at its maximum power point at the third hybrid operating mode, and the rotation speed of the second motor/generator decreases as the vehicle speed increases. Therefore, the vehicle can be driven within a drive limit range of the motor. Since the engine mode is provided, the vehicle can run with high speed without electric load of the first and second motor/generators. Therefore, fuel economy may be improved.

The foregoing descriptions of specific exemplary embodiments of the present invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed, and obviously many modifications and variations are possible in light of the above teachings. The exemplary embodiments were chosen and described in order to explain certain principles of the invention and their practical application, to thereby enable others skilled in the art to make and utilize various exemplary embodiments of the present invention, as well as various alternatives and modifications thereof. It is intended that the scope of the invention be defined by the Claims appended hereto and their equivalents.

What is claimed is:

1. A power transmission system of a hybrid electric vehicle comprising:

- an input shaft receiving torque of an engine;
- a first rotation shaft disposed in parallel with the input shaft;
- a second rotation shaft disposed in parallel with the input shaft and enclosing at least a part of the first rotation shaft;
- a first planetary gear set disposed on the second rotation shaft, and including a first rotation element directly connected to a first motor/generator, a second rotation element connected to an output gear through the second rotation shaft, and a third rotation element connected to the input shaft through a first transfer gear; and
- a second planetary gear set disposed on the first rotation shaft, and including a fourth rotation element connected to a second motor/generator through the first rotation shaft and selectively connected to the input shaft through a second transfer gear, a fifth rotation element connected to the second rotation element, and a sixth rotation element selectively connected to a transmission housing.

2. The power transmission system of claim 1, wherein the first planetary gear set is a single pinion planetary gear set, and includes a first sun gear being the first rotation element, a first planet carrier being the second rotation element, and a first ring gear being the third rotation element, and wherein the second planetary gear set is a single pinion planetary gear set, and includes a second sun gear being the fourth rotation element, a second planet carrier being the fifth rotation element, and a second ring gear being the sixth rotation element.

3. The power transmission system of claim 1, wherein the first planetary gear set is a double pinion planetary gear set, and includes a first sun gear being the first rotation element, a first ring gear being the second rotation element, and a first planet carrier being the third rotation element, and wherein the second planetary gear set is a single pinion planetary gear set, and includes a second sun gear being

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the fourth rotation element, a second planet carrier being the fifth rotation element, and a second ring gear being the sixth rotation element.

4. The power transmission system of claim 1, wherein the first planetary gear set is a single pinion planetary gear set, and includes a first sun gear being the first rotation element, a first planet carrier being the second rotation element, and a first ring gear being the third rotation element, and

wherein the second planetary gear set is a double pinion planetary gear set, and includes a second sun gear being the fourth rotation element, a second ring gear being the fifth rotation element, and a second planet carrier being the sixth rotation element.

5. The power transmission system of claim 1, further comprising:

a first clutch disposed between the first rotation shaft and the second rotation shaft;

a second clutch disposed between the input shaft and the second transfer gear; and

a first brake disposed between the sixth rotation element and the transmission housing.

6. The power transmission system of claim 5, wherein the first brake is operated at a first EV mode, the first clutch is operated at a second EV mode, the first brake is operated at a first hybrid operating mode, the first clutch is operated at a second hybrid operating mode, the second clutch is operated at a third hybrid operating mode,

the second clutch and the first brake are operated at a first engine mode, and

the first clutch and the second clutch are operated at a second engine mode.

7. The power transmission system of claim 1, wherein a third clutch is disposed between the engine and the input shaft.

8. The power transmission system of claim 1, further comprising:

a first clutch disposed between the first rotation shaft and the second rotation shaft;

a second clutch disposed between the second transfer gear and the first rotation shaft; and

a first brake disposed between the sixth rotation element and the transmission housing.

9. A power transmission system of a hybrid electric vehicle comprising:

an input shaft receiving torque of an engine;

a first rotation shaft disposed in parallel with the input shaft;

a second rotation shaft disposed in parallel with the input shaft and enclosing at least a part of the first rotation shaft;

a first planetary gear set including a first rotation element directly connected to a first motor/generator, a second rotation element connected to an output gear through the second rotation shaft, and a third rotation element connected to the input shaft;

a second planetary gear set including a fourth rotation element connected to a second motor/generator and selectively connected to the input shaft, a fifth rotation element connected to the second rotation element, and a sixth rotation element selectively connected to a transmission housing;

a first transfer gear connecting the input shaft to the third rotation element; and

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a second transfer gear connecting the input shaft to the fourth rotation element.

10. The power transmission system of claim 9, wherein the first planetary gear set is a single pinion planetary gear set, and includes a first sun gear being the first rotation element, a first planet carrier being the second rotation element, and a first ring gear being the third rotation element, and

wherein the second planetary gear set is a single pinion planetary gear set, and includes a second sun gear being the fourth rotation element, a second planet carrier being the fifth rotation element, and a second ring gear being the sixth rotation element.

11. The power transmission system of claim 9, wherein the first planetary gear set is a double pinion planetary gear set, and includes a first sun gear being the first rotation element, a first ring gear being the second rotation element, and a first planet carrier being the third rotation element, and

wherein the second planetary gear set is a single pinion planetary gear set, and includes a second sun gear being the fourth rotation element, a second planet carrier being the fifth rotation element, and a second ring gear being the sixth rotation element.

12. The power transmission system of claim 9, wherein the first planetary gear set is a single pinion planetary gear set, and includes a first sun gear being the first rotation element, a first planet carrier being the second rotation element, and a first ring gear being the third rotation element, and

wherein the second planetary gear set is a double pinion planetary gear set, and includes a second sun gear being the fourth rotation element, a second ring gear being the fifth rotation element, and a second planet carrier being the sixth rotation element.

13. The power transmission system of claim 9, further comprising:

a first clutch disposed between the first rotation shaft and the second rotation shaft;

a second clutch disposed between the input shaft and the second transfer gear; and

a first brake disposed between the sixth rotation element and the transmission housing.

14. The power transmission system of claim 13, wherein the first brake is operated at a first EV mode, the first clutch is operated at a second EV mode, the first brake is operated at a first hybrid operating mode, the first clutch is operated at a second hybrid operating mode,

the second clutch is operated at a third hybrid operating mode,

the second clutch and the first brake are operated at a first engine mode, and

the first clutch and the second clutch are operated at a second engine mode.

15. The power transmission system of claim 9, wherein a third clutch is disposed between the engine and the input shaft.

16. The power transmission system of claim 9, further comprising:

a first clutch disposed between the first rotation shaft and the second rotation shaft;

a second clutch disposed between the second transfer gear and the first rotation shaft; and

a first brake disposed between the sixth rotation element and the transmission housing.

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